Q(2)

Sec (4)

d] Density of States $\rho_{c,v}(E)$ for 2D Structure (Quantum well)

↳ Assume $L_x = L_y = 1mm$, $L_z = 10 A^o$

$$k_x = \frac{m\pi}{L_x} \qquad m = 1, 2, 3, \ldots$$

$$k_y = \frac{p\pi}{L_y} \qquad p = 1, 2, 3, \ldots$$

$$k_z = \frac{q\pi}{L_z} \qquad q = 1, 2, 3, \ldots$$

if $L_z = 10 A^o$

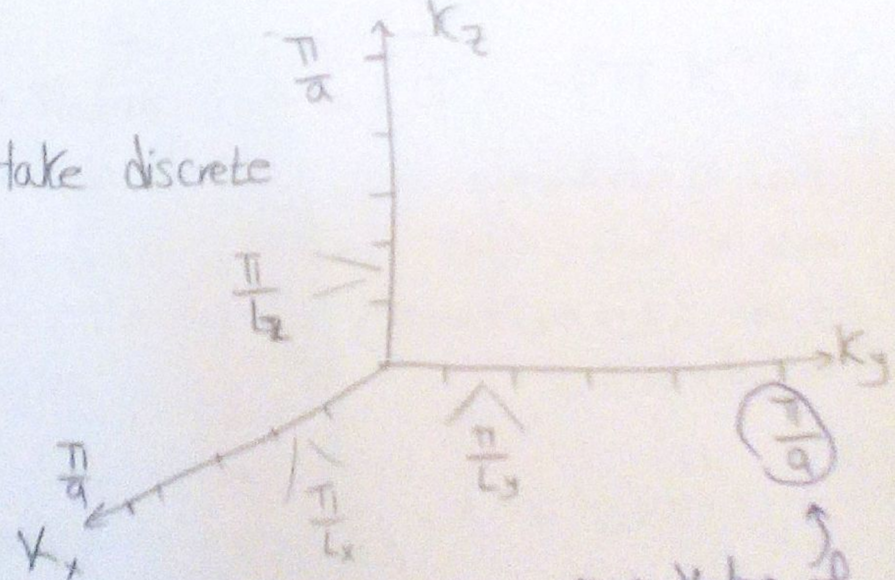
↳ Then k_z will take discrete Values

for example:

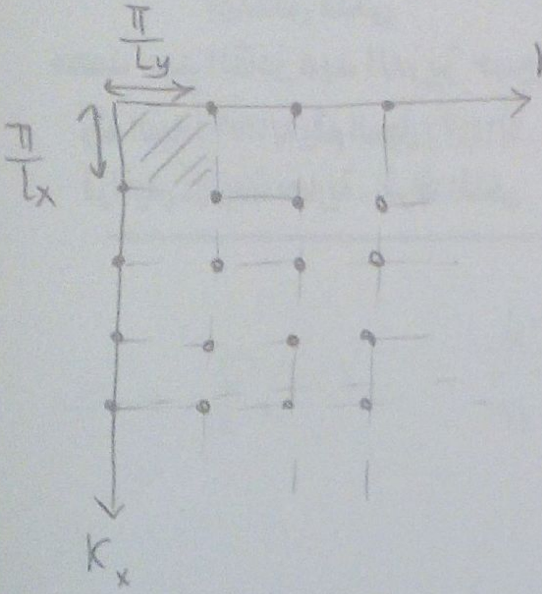
$$k_z\Big|_{q=1} = \frac{\pi}{L_z} = \frac{\pi}{10}$$

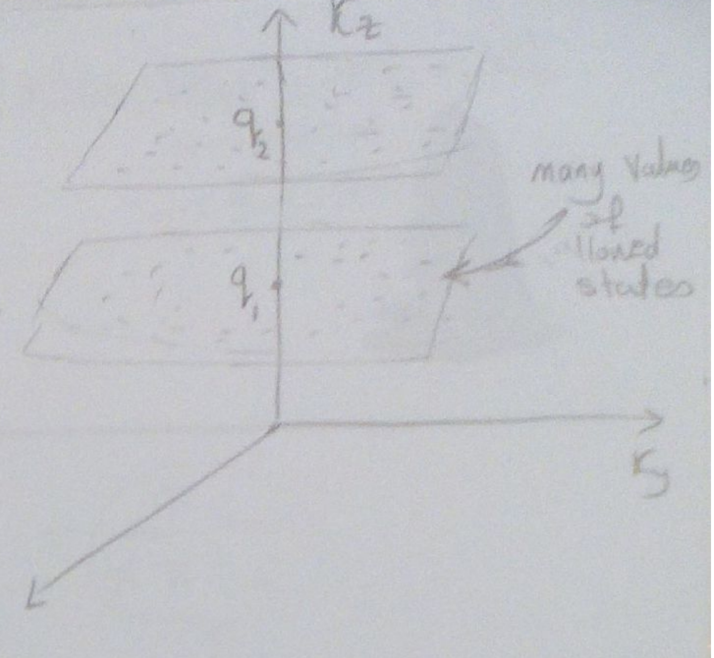
$$k_z\Big|_{q=2} = \frac{2\pi}{10} = \frac{\pi}{5}$$

$a = 5 A^o$ in Semi Conductor



max Value of K in 1st Brillouin Zone





↪ Area of one state $= \left(\frac{\pi}{L_x}\right)\left(\frac{\pi}{L_y}\right)$

↪ Area of all allowed states (up to E_n) $= (\pi K^2) \cdot \frac{1}{4}$

لكل قيمة K هناك قيمة لـ E

Vector in 2D

يرسم دائرة يبقى عندى دائرة نصف قطرها (K)

أخذ الاتجاه الموجب فقط من المحاور (+K)

لأن اتجاه (-K) هو اتجاه رجوع

Spin of electron

↪ No. of Allowed states $= \frac{\pi K^2}{4(\pi^2)} \cdot (L_x L_y) = 2 \times \frac{K^2 L_x L_y}{4\pi}$

$$N|_{\text{per unit volume}} = \frac{K^2 L_x L_y}{4\pi (L_x L_y L_z)} = \frac{K^2}{2\pi L_z}$$

$$f(E) = \frac{dN}{dE} = \frac{dN}{dk} \cdot \frac{1}{dE/dk}$$

$$\therefore N = \frac{K^2}{4\pi L_z} \Longrightarrow \frac{dN}{dk} = \frac{2K}{2\pi L_z} = \frac{K}{\pi L_z}$$

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CB]

$$E = E_c + \frac{\hbar^2 k^2}{2m_c} \qquad |k^2| = \cancel{2k_x^2} + k_y^2 + k_z^2$$

$$= \cancel{2k_t^2 + 2k_z^2}$$

$$\frac{dE}{dk} = \frac{2k\hbar^2}{2m_c} = \frac{k\hbar^2}{m_c}$$

$$\rho(E) = \frac{\cancel{k}}{\pi L_z} \cdot \frac{m_c}{\cancel{k}\hbar^2} = \frac{m_c}{\hbar^2 \pi L_z}$$

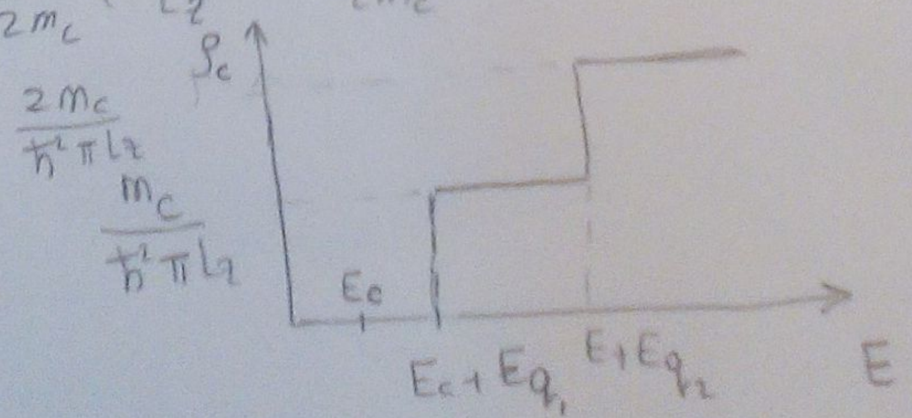
Constant doesn't depend on k

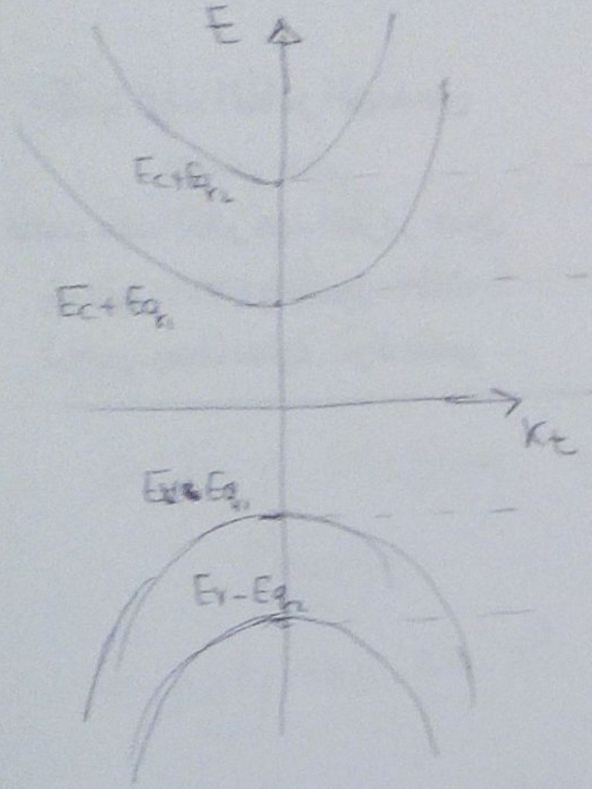
$$E = E_c + \frac{\hbar^2 (k_x^2 + k_y^2 + k_z^2)}{2m_c}$$

$$= E_c + \frac{\hbar^2 k_z^2}{2m_c} + \frac{\hbar^2 (k_x^2 + k_y^2)}{2m_c}$$

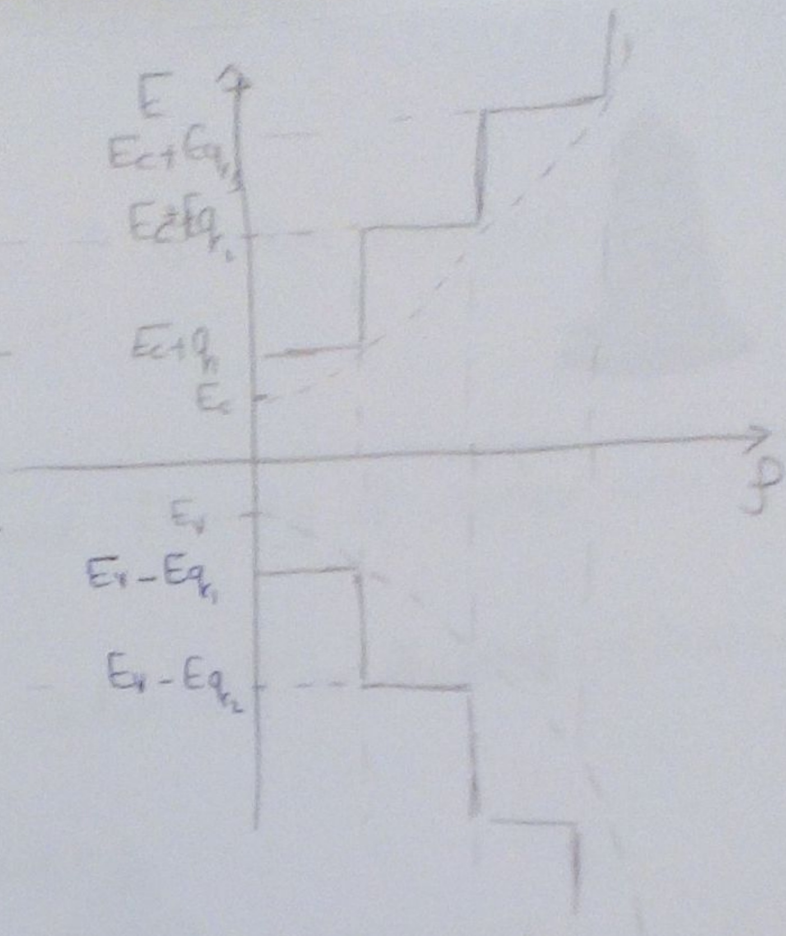
$$= E_c + \frac{\hbar^2}{2m_c}\left(\frac{q\pi}{L_z}\right)^2 + \frac{\hbar^2 k_t^2}{2m_c}$$

$$E_1 = E_c + \frac{\hbar^2}{2m_c}\left(\frac{\pi}{L_z}\right)^2 + \frac{\hbar^2 k_t^2}{2m_c} = E_c + E_{q_1} + \frac{\hbar^2 k_t^2}{2m_c}$$





E
$E_c+E_{q_{r_2}}$
$E_c+E_{q_{r_1}}$
k_t
$E_v-E_{q_{r_1}}$
$E_v-E_{q_{r_2}}$



E
$E_c+E_{q_{r_3}}$
$E_c+E_{q_{r_2}}$
$E_c+q_{r_1}$
E_c
ρ
E_v
$E_v-E_{q_{r_1}}$
$E_v-E_{q_{r_2}}$

Q(4)

$\boxed{b}$ Repeat the solution of (a) when dimensions of structure doubles?

~Sol

\# E-k Diagram and Density of states won't change

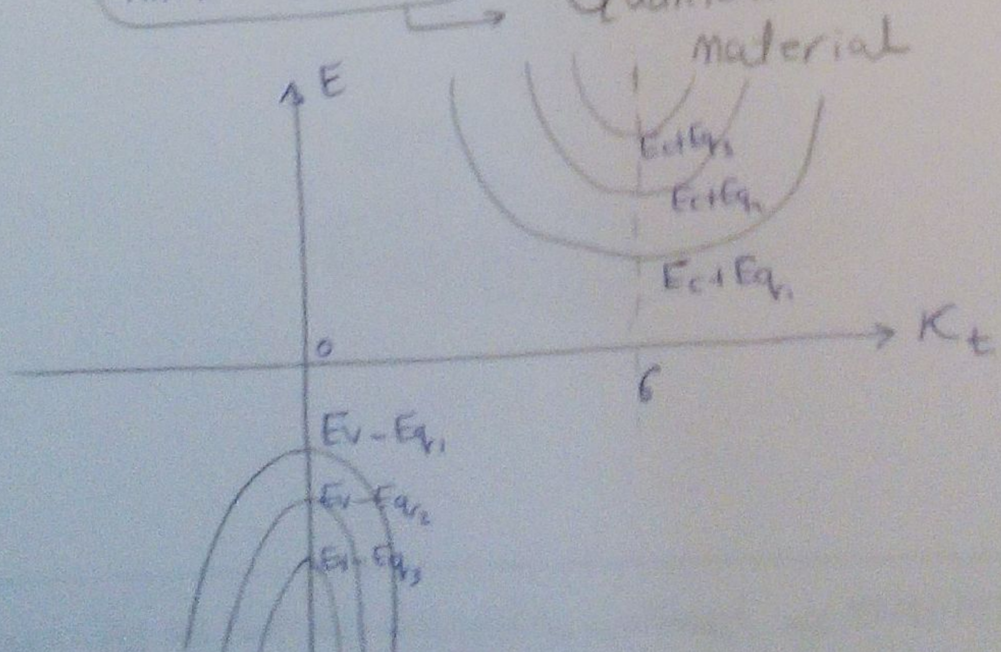
\# only the No. of states will be increased

$$N = N * \text{Volume}$$

$$= 10^{19} * (0.2)^3 = 8 * 10^{16} \text{ states}$$

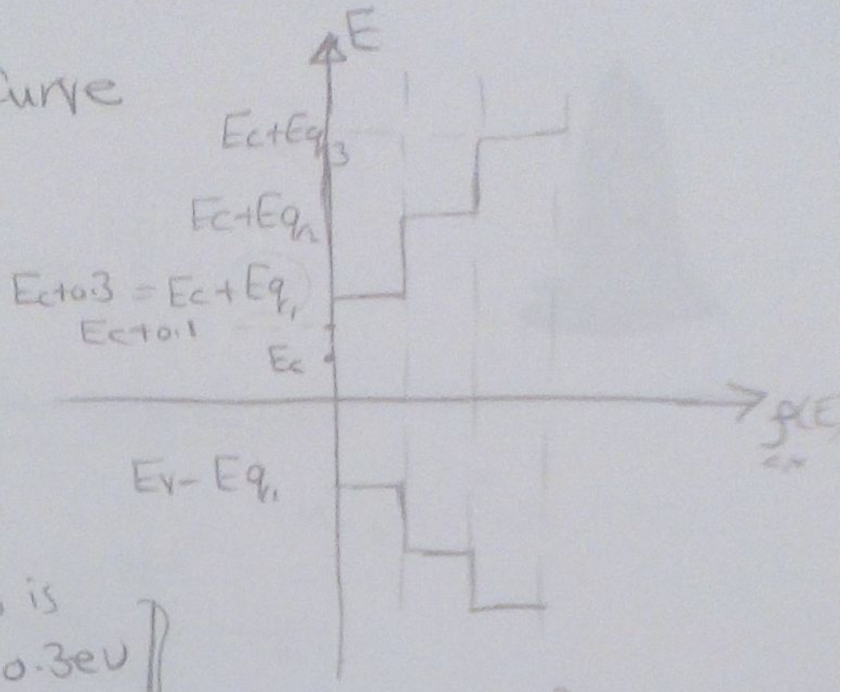
Q(4) $\boxed{c}$ Repeat the solution of ⓐ when dimensions of structure changed to be

1mm * 1mm * 10 A° → Quantum well not Bulk material



↪ Density of State Curve

$$\rho(E) = \frac{m_c}{\hbar^2 \pi L_z}$$



↪ No. of States from

$E_c \longrightarrow E_c + 0.1 eV$

∵ Small energy in C.B is

$E_c + E_{q_1} = E_c + 0.3 eV$

∴ $\rho(E)$ in this reigon = zero

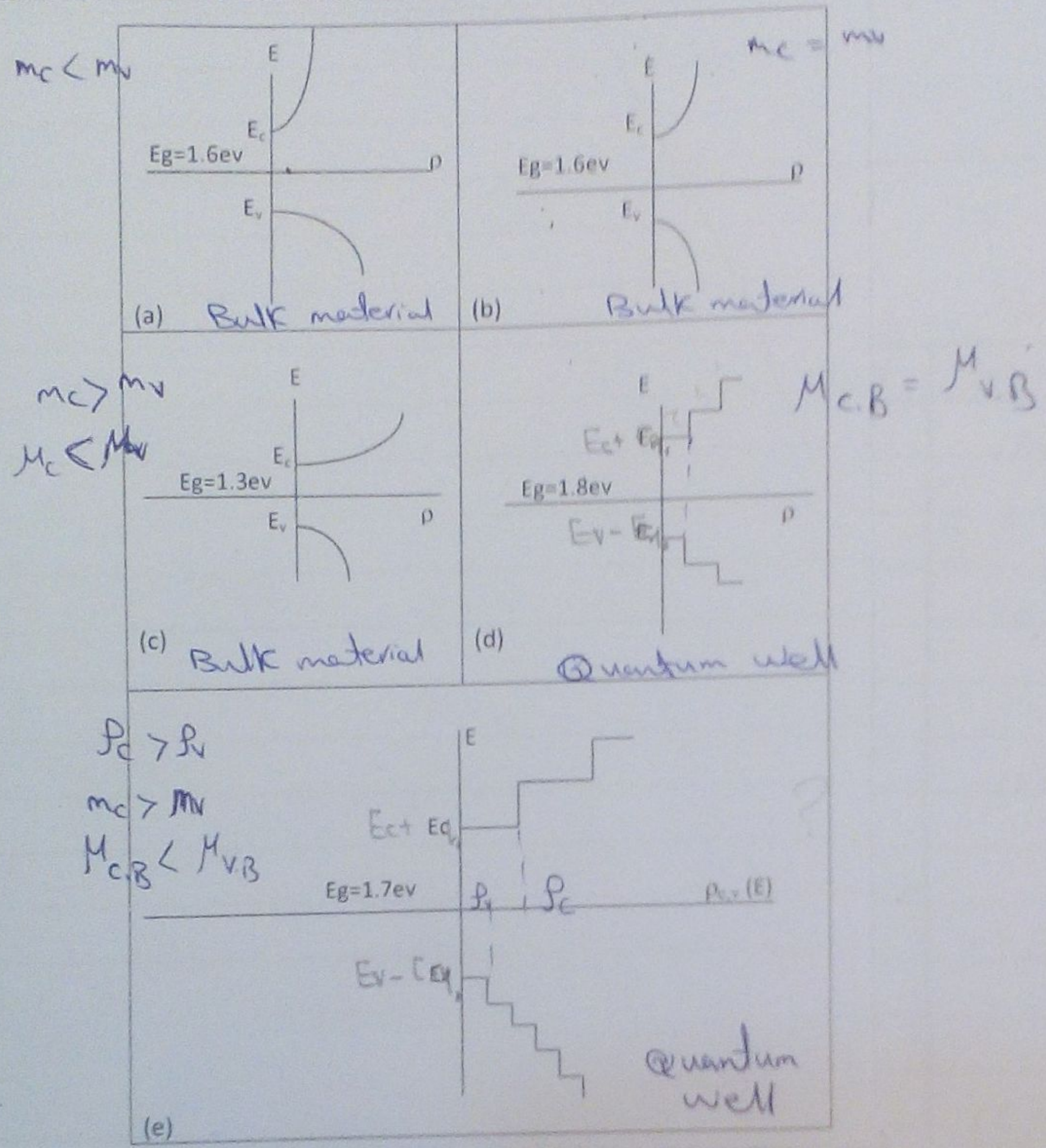
$$E_{q_1} = \frac{\hbar^2}{2m_c}\left(\frac{\pi}{L_z}\right)^2$$

$$= \frac{(1.05*10^{-34})^2}{2*0.98*9.1*10^{-31}}*\left(\frac{\pi}{10*10^{-9}}\right)^2$$

$$= 6.1*10^{-20} \text{ J}$$

$$\boxed{E_{q_1} = 0.38 \text{ eV}}$$

Q_3. Given the following curves for $\rho_{c,v}(E)$



a) Determine the type of each structure based on its given density of states

b) Draw E-K diagram qualitatively for each material described by its density state.

c) Comment on the carriers ~~mobilites~~ Mobilities in each figure.

d) Estimate the values ($E_{m1}, E_{m2}, E_{p1}, E_{p2}, E_{q1}$ and E_{q2})in curve (d) assuming structure dimensions are 1mm ×5mm ×8A and m_c=.067m_0, $m_0 = 9.1\times10^{-31}$ kg

e) Using the information given in (d) calculate the density of states per unit volume at

i)$E=E_c+E_{q1}/2$ ii) $E=E_c-E_{q1}/2$ iii) $E=E_c+1.5\,E_{q1}$ iv) $E=E_c+2E_{q1}$

f) Using the information given in (d) calculate the number of allowed state within the whole structure for energy ranging from i) E_c to $E_c+E_{q1}/2$ ii) E_c+E_{q1} to E_c+2E_{q1}

g) Estimate the values of allowed states per unit volume for structure represented by curve (a) at energies (a)E_v-.1ev (b)E_c+0.1ev (c) E_c, assuming m_e=.08m_0 and m_v=0.28m_0

h) Estimate ~~the total~~ number of allowed states in the conduction band in structure represented by curve (a) assuming their dimensions are 1mm × 5mm × 3mm. Ec + 2eV

9

Q(3) [d] Estimate the Values (E_{m_1}, E_{m_2}, E_{P_1}, E_{P_2}, E_{q_1}, E_{q_2})

in Curve (d) assuming Dimensions are

$1mm * 5mm * 8A°$, $m_c = 0.067\, m_o$

$m_o = 9.1 * 10^{-31}$ Kg

-Sol-

1) $E_{m_1} = \frac{\hbar^2}{2m_c} \left(\frac{\pi}{L_x}\right)^2 = \frac{(1.05*10^{-34})^2}{2*0.067*9.1*10^{-31}} * \left(\frac{\pi}{1*10^{-3}}\right)^2$

$= \checkmark$ J

2) $E_{m_2} = \frac{\hbar^2}{2m_c} \left(\frac{2\pi}{L_x}\right)^2 = 4 *$ نفس القيمة $=$

3) $E_{P_1} = \frac{\hbar^2}{2m_c} \left(\frac{\pi}{L_y}\right)^2 = \checkmark$

4) $E_{P_2} = \frac{\hbar^2}{2m_c} \left(\frac{2\pi}{L_y}\right)^2 = 4* = \checkmark$

5) $E_{q_1} = \frac{\hbar^2}{2m_c} \left(\frac{\pi}{L_z}\right)^2$

6) $E_{q_2} = \frac{\hbar^2}{2m_c} \left(\frac{2\pi}{L_z}\right)^2 = 4 * \left(\frac{\hbar * \pi}{L_z}\right)^2 \cdot \frac{1}{2m_c}$

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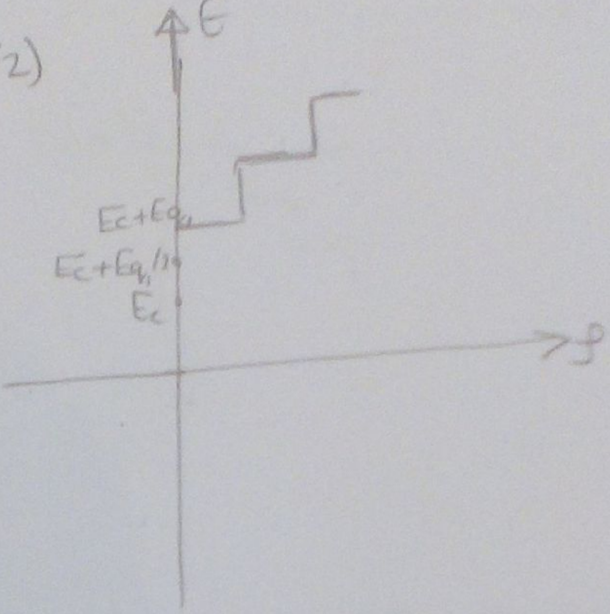
[F] Using the information given in (d) Calculate the no. of allowed state within the whole structure for energy ranging from i) $E_c \to E_c + E_{q_1}/2$
ii] $E_c \to E_c + E_{q_1}$
iii] $E_c \to E_c + 2E_{q_1}$



i] $N \to (E_c \to E_c + E_{q_1}/2)$

$\boxed{N = \text{zero}}$

ii] $E_c \to E_c + E_{q_1}$

$\boxed{N = 0}$

iii] $N = \int_{E_c}^{E_c+2E_{q_1}} \rho(E)\, dE$

per unit volume

$$= \int_{E_c+E_{q_1}}^{E_c+2E_{q_1}} \rho(E)\, dE = \frac{m_c}{\pi \hbar^2 L_z}\left[E_c + 2E_{q_1} - E_c - E_{q_1}\right]$$

$$= \frac{m_c}{\pi \hbar^2 L_z} E_{q_1}$$

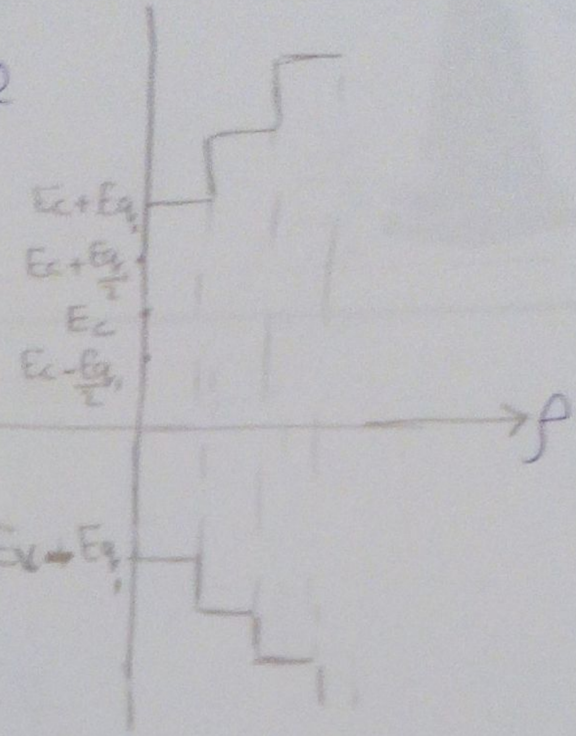
$$= \frac{0.067 * 9.1 * 10^{-31}\ (3.55 * 10^{-28})}{\pi (1.05 * 10^{-34})^2 (8 * 10^{-10})}$$

$$= 7.7 * 10^{17}\ m^{-3}$$

$N = 7.7 * 10^{17} * (1 * 10^{-3} * 5 * 10^{-3} * 8 * 10^{-10})$

$N = 3.1 * 10^{3}$ state

$\boxed{e}$ Using the information given in $\boxed{d}$ Calculate the density of states per unit Volume at



i) $E = E_c + E_{q_1}/2$

$\hookrightarrow \rho(E) = 0$

ii) $E = E_c - E_{q_1}/2$

$\hookrightarrow \rho(E) = 0$

$\boxed{iii}$ $E = E_c + 1.5\, E_{q_1}$

$$\hookrightarrow \rho_c(E) = \frac{m_c}{\pi \hbar^2 L_z} = \frac{0.067 * 9.1 * 10^{-31}}{\pi * (8*10^{-12})(1.05*10^{-34})^2}$$

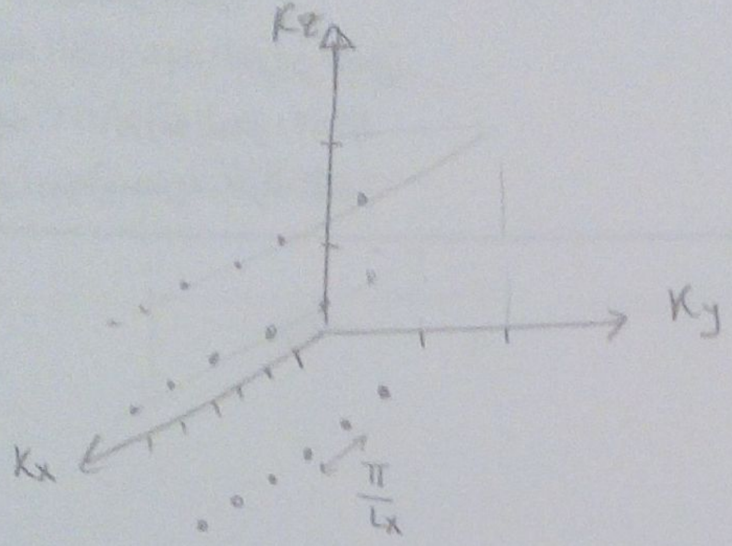
$$= 2.2 * 10^{45}\ m^{-3}$$

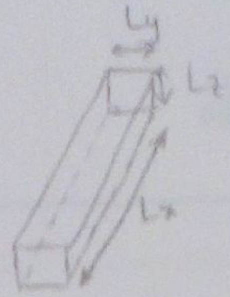
$$= 2.2 * 10^{39}\ cm^{-3}$$

$\boxed{iv}$ $E = E_c + 2E_{q_1}$

$$\rho_c(E) = \frac{m_c}{\pi \hbar^2 L_z} = 2.2 * 10^{39}\ cm^{-3}$$

e] Density of States $\rho_{c,v}(E)$ for 1D structure (Nano wire)





↪ length of one state $= \frac{\pi}{L_x}$

↪ In 2D → Area
↪ In 3D → Volume
↪ In 1D → length

↪ length of all allowed state $= K * \frac{1}{2}$

لأن الموجب فقط

↪ $N = 2 * K * \frac{1}{2} = K$

Spin of electron

↪ N / per unit Volume $= \dfrac{K}{\frac{\pi}{L_x}} = \dfrac{L_x K}{\pi (L_x L_y L_z)} = \dfrac{K}{\pi L_y L_z}$

↪ $\rho(E) = \dfrac{dN}{dk} \cdot \dfrac{1}{dE/dk} = \dfrac{1}{\pi L_y L_z} \cdot \dfrac{m_c}{\hbar^2 K}$

$$E = E_c + \frac{\hbar^2 K^2}{2 m_c}$$

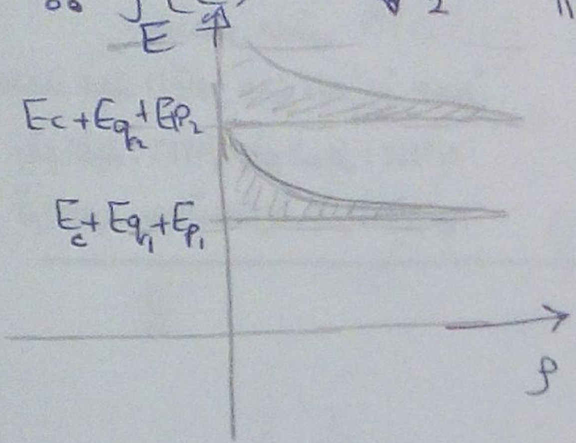
$$\frac{dE}{dk} = \frac{\hbar^2 K}{m_c}$$

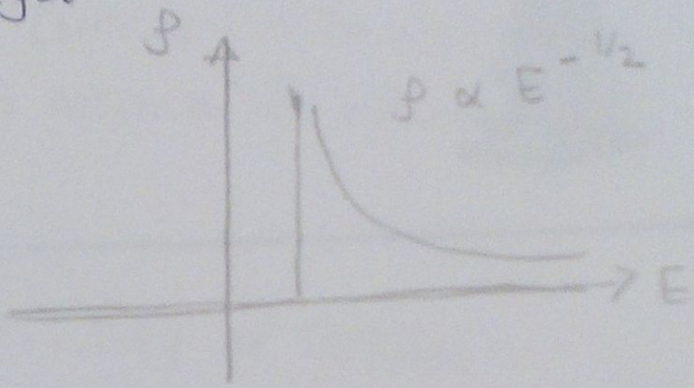
$$\therefore K = (E - E_c)^{\frac{1}{2}} \left(\frac{2 m_c}{\hbar^2}\right)^{\frac{1}{2}}$$

$$\therefore \rho(E) = \frac{1}{\pi L_y L_z} \left(\frac{m_c}{\hbar^2}\right) (2)^{-\frac{1}{2}} \left(\frac{m_c}{\hbar^2}\right)^{-\frac{1}{2}} (E - E_c)^{-\frac{1}{2}}$$

$$= \frac{1}{\sqrt{2}\, \pi L_y L_z} \left(\frac{m_c}{\hbar^2}\right)^{\frac{1}{2}} (E - E_c)^{-\frac{1}{2}}$$

$$\therefore \ \rho(E) = \sqrt{\frac{m_c}{2}} \cdot \frac{1}{\pi \hbar L_y L_z} \cdot (E - E_c)^{-1/2}$$





Mobility

Ability of Carriers (holes / electrons) to move in response of electric field.

$$\mu = \frac{q}{m^* f_c}$$

f_c ← freq. of Collision

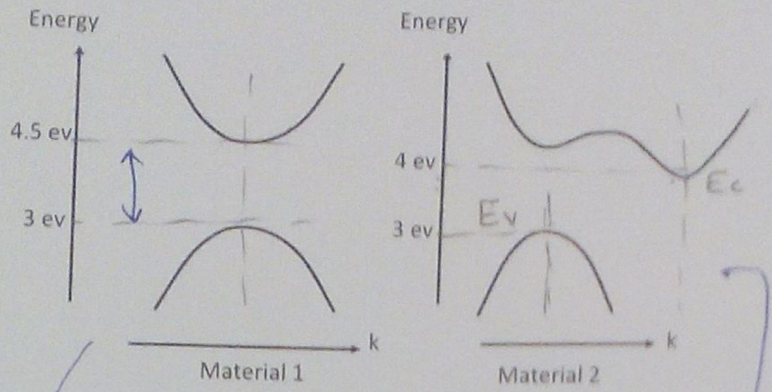
$$\boxed{\mu = \frac{q\tau}{m^*}}$$

τ ← متوسط الزمن بين تصادمين متتاليين

$$\mu \propto \frac{1}{m^*}$$

From sheet (1)

Q10. Determine the characteristics (mobility, effective mass, direct or indirect and the energy bandgap) of two semiconductor materials using their corresponding E-k Diagrams shown below.



$E_g = 1\,ev$

peaks occur at differant (K)

Direct Band Gap

$E_g = 1.5\,ev$

Indirect Band gap

Effective mass

$m_c = m_v$

as Curvature of C.B $\simeq$ Curvature of V.B

Curvature of C.B > V.B

$m_c < m_v$

Mobility

$\mu_{C.B} = \mu_{V.B}$

$\boxed{\mu_c > \mu_v}$

Summary of Lec (1)

Q1. Complete the following sentences

1. The characteristics of the deflector can be altered by applying .... Sound
2. The characteristics of the .... devices can be altered by applying magnetic fields — Magento optic
3. The characteristics of the Electro optic .... can be altered by applying electric fields.
4. Optical electronics are defined as .... devices interact with Light
5. Optical circuit board communications are necessary for .... optical Isolation
6. Optical electronic chips are composed of Photo detector .... and .... Laser diode
7. Optoelectronic devices are based on the Semi Conductor materials that have electrical conductivities within the range .... 10^{-6} .... to .... 10^{3}
8. The electrical conductivities of the semiconductor materials can be altered by .... Temperature, Doping .... and .... Illumenation

Hint: see lecture 1

Semi Conductor Materials

Semi Conductor	Bandgap energy E_g (e.V)
1 Silicon Si	1.1 eV
2 Germanium Ge	0.67 eV
3 Gallium Arsenide GaAs	1.42 e.V

Plank – Einstien Relation

∴ Energy of photon $= E = h \cdot f \leftarrow$ freq. $= h \frac{c}{\lambda}$

planck constant

$$\therefore \boxed{\lambda = h \cdot \frac{c}{E}}$$

→ To transfer electron from Valence band to Conduction band → we need photon with Absorbed

$$E_{ph} > E_g$$

→ When electron Loss its energy and return to Valence band → it emit photon

$$E_{ph} > E_g$$

Note

→ SemiConductor at $T = 0°K$ → like insulator

لأنه لا يوجد الكترونات في ال Conduction Band وكل الالكترونات في ال Valence

② at $T = 300°K$ → $E = K \cdot T = 0.025$ eV

→ Consentration of Carrier in

عدد الالكترونات في ال Conduction Band عند درجة حرارة (300K)

- Si → $n_i \approx 10^{10}\ cm^{-3}$
- GaAs → $n_i \approx 10^{6}\ cm^{-3}$
- Ge → $n_i \approx 10^{13}\ cm^{-3}$